THE BATTERY HANDBOOK

ASESOR

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When Ratelco became the first Motorola two-way radio service station in the United States in 1945, the company began its subsequent involvement in what could be termed "battery-oriented technology."

Very quickly, Ratelco became a source of backup systems for mobile radio installation. From there, the development of other families of products was a simple case of evolution. Industry was seeking more reliable battery chargers and Ratelco was among the manufacturers who responded to that need. Several technologies have come and gone, fallen out of favor for one reason or another. Ratelco has consistently been in the forefront as this progress has been made. As battery charger technology has advanced to meet the needs of industry, other new products have emerged and are now part of Ratelco's line. All, however, are related to one another.

For instance, the communications industry requires standby systems with battery chargers which are filtered to virtually eliminate noise. Precision charging equipment and communication power assemblies (DC power boards) evolved from that need. That same industry requires uninterruptible power systems (UPS) that can switch a load in case of AC power failure in 4 mSEC and can "condition" power against line disturbances of all sorts. Ratelco manufactures these products and others, such as inverters, converters and power supplies.

This booklet will tell you just about all we can tell you about batteries. We hope you will find it informative and useful.

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BATTERIES: AN OVERVIEW

Batteries are taken for granted. Everyone has one in his automobile and is aware of it only when his car fails to start on a cold winter morning. He expects to replace that battery about every 3 years, for about $30. In fact, a battery which is guaranteed for life can be purchased for under $100—a manageable expense. Batteries for commercial use, however, are of a different breed. For instance, a Ratelco Uninterruptible Power Supply (UPS) installed to power a 5000-watt load for 15 minutes would require a battery costing up to $4500, if it were nickel-cadmium, or about $1700 if it were lead-acid type—a much more formidable investment justifying proper care.

Commercial applications most commonly use lead-acid batteries; this handbook, therefore, will be concerned mainly with this type.

WHERE DOES RATELCO FIT?

Ratelco's products are intimately linked with batteries: (1) We supply chargers for all makes and types of rechargeable batteries; (2) We may include batteries as part of the UPS package, so the size and type of battery selected are critical. It's to our advantage that the best battery choice be made by our customers.

LEAD-ACID BATTERIES: SOME BACKGROUND

Today's rechargeable battery was born in 1859 when an Englishman by the name of R.L.G. Plante began experimenting with two strips of pure lead immersed in electrolyte, a weak sulfuric acid solution. Expecting to obtain a potential difference and failing to do so, Plante then applied a voltage potential to the two strips of lead for some length of time. He noticed a difference occurring in the strips—the strip connected to the positive lead had taken on a brownish hue, while the other took on a spongy appearance. Also, when the power supply was removed, a potential difference of 2.0 volts remained and Plante was able to draw a weak current from it. Lead peroxide had formed on the positive strip and sponge lead on the negative strip. After the charge was removed the lead strips reverted to their original form. Plante had invented the secondary storage cell, which differs from the primary cell of volts in that a charge must be put in before it can be taken out.

In 1881 a man named Faure devised a method of forming plates of lead from a paste compound. This greatly increased the capacity of Plante's battery, but the lead-oxide paste plates had their own problems. The active elements of lead have no strength and, in their pure state, wash away in the electrolyte. To solve this problem various alloys of lead were tried. An alloy containing 8-12% antimony was found to offer the best results; it was so successful that it is still used today.

HOW A BATTERY WORKS

A battery is made up of various quantities of receptacles called cells.

Each cell's case encompasses plates (grids), electrolyte, plate separators and interconnectors. By taking a look at a battery's characteristics in terms of each component's function, an understanding of a battery's strengths and limitations in performance can be developed.

Voltage

The voltage of a cell is determined by its plate material and electrolyte. Some typical voltages, based on cell composition, are given in Table 1.

Table 1

Electrochemical Cell Voltages

Lead-acid	2.0 volts per cell
Nickel-cadmium	1.2 volts per cell
Nickel-iron	1.2 volts per cell
Silver-zinc	1.5 volts per cell

This voltage does not depend on the size of the plate, nor on the number of plates within a cell; it is determined only by the electrochemical system used—the plate materials themselves. The voltage of the entire battery is the sum of the voltage of cells in series in the battery.

Energy storage capacity

The energy storage capacity of a cell is determined both by the plate materials and electrolyte and, contrary to voltage, by the size of the cell itself. Energy, which is generally shown in watt-hours, can also be given as volts × amps × time. A battery is sized in terms of amp-hours, and assuming that the discharge voltage is relatively constant, the energy content of the battery can be considered to be directly proportional to its amp-hour capacity, where amp-hours is the number of amps the battery can supply over a given period of time (generally 8 hours) multiplied by the period of time. Some typical energy densities are given in Table 2.[1]

Table 2

Battery System Energy Density

Lead-acid	13.1-15 watt hours per pound
Nickel-cadmium	11-11.5 watt hours per pound
Silver-zinc	85-100 watt hours per pound

These figures point out that plate construction—and, by extension, the separator construction—is quite important in battery performance.

Current

Charge and discharge current is determined mainly by the

1. Electrochemical system
2. Plate size and construction
3. Separator design
4. Temperature

Which electrochemical system is used—nickel-cadmium, lead-acid, etc.—determines the plate construction techniques, which are a major factor in charge and discharge rates.

Another factor is the part the electrolyte plays in the cell. For example, the potassium hydroxide electrolyte in nickel-cadmium cells is not directly involved in the chemical reaction, thus diffusion in the electrolyte is not an important determinant in charge or discharge rates. In lead-acid batteries, however, the electrolyte is an integral part of the charge-discharge chemical reaction, so diffusion is very important. As the plates charge, the electrolyte next to the plates changes to almost pure sulfuric acid. Being heavier than the remaining electrolyte, the sulfuric acid drifts to the bottom of the cell and is replaced by low specific gravity electrolyte. Since in lead-acid cells the chemical reaction takes place at the point where the electrolyte contacts the lead of the plates, surface area of the plates is very important in current flow—the greater the surface area, the greater the available current. Referring again to Table 2, one can see that energy is a function of weight. This creates a conflict: Maximum current flow requires maximum plate surface area and maximum porosity; maximum power (amp-hours) requires maximum weight (minimum porosity). Battery design is thus a continual compromise between maximum amp-hours and maximum discharge current.

Plates

In a lead-acid battery, the plates are made up of (1) grid and (2) paste, both important components. The grid, pure lead or an alloy of lead, is used mainly to hold the paste in place. The paste, the active material which holds the charge, is made up of lead dust, sulfuric acid and possibly some type of fiber to increase strength and reduce mud formation. The negative plate may have other substances, such as barium or strontium sulfate, lampblack and organic additives, to improve discharge performance and prevent capacity loss during repeated cycling.

The density and porosity of the paste, along with the physical dimensions of the plate, determine the capacity and discharge rate of the plate. If high discharge rates are desired the plate is made thin and the paste porous. If high capacity with lots of cycle life is desired the plates are made thicker and the paste more dense.

Automotive batteries have very thin plates (about $\frac{1}{8}$") so that a great number can be put in the case to provide high starting currents. But an automotive battery will not withstand many deep discharge cycles. Stationary batteries, on the other hand, tend to have thick plates (about $\frac{1}{4}$") and denser pastes to give higher amp-hours and tolerate more deep discharge cycles.

Pure lead would be ideal for the grid material except for its lack of physical strength. As pure lead is soft and cannot be made to hold its shape, an alloying agent is added to increase the mechanical strength of the grid. In the last century 8-12% alloys of antimony were determined to be the best available, and became widely used for a hard, easily manufactured grid; unfortunately the combination also had a comparatively short life.

With battery usage, the antimony in the positive grid will leach out and migrate over to the negative plate where it coats the active material and "poisons" the plate, lowering its capacity and causing increasing water usage in the battery. This characteristic of lead-antimony batteries effectively shortens their life span to about 15-20 years. The impending demise of a lead-antimony battery is indicated by accelerating water usage and lowered capacity.

Not until the 1950s, when Bell Laboratories developed a lead-calcium grid which eliminated the slow poisoning of the negative plate, were significant steps taken to solve this short-life problem. Bell scientists found that an alloy of less than 0.1% calcium provided a hard grid in which the alloying material would not hinder the chemistry of the battery. But again there were drawbacks: the grid was difficult to manufacture, and it would grow in size as the battery was cycled. Still, even with the undesirable growth of the positive plate battery life could be extended to 20-30 years.

The most long-lived grid remains that made of pure lead. Recent developments in lead-acid battery technology have brought about the round battery, which uses pure lead grids and has life expectancy of over 30 years. Usage of this battery, now confined to the telephone industry, may spread as time goes on. Other pure lead grids are in wide use in other parts of the world. In Europe, for instance, the "Plante plate" is preferred for stationary service. Not all Plante plates are pure lead, and many have grids of lead-antimony. However the pure lead Plante plate has the advantage of long life but carries with it the penalties of low energy density and high specific lead density.

Separators

One major function of the separators is to separate the positive plates from the negative plates. To do this seemingly simple task, separators must have[2]

(1) chemical stability against sulfuric acid

(2) structural stability when wetted with acid—little tendency to shrink or swell

(3) little influence on the electrolytic resistance

(4) no electronic conductivity

(5) good wettability

(6) mechanical strength

(7) low specific density

(8) low material and manufacturing cost

Separators also hold active material on the plates, keeping it from falling to the bottom of the cell as mud.

Battery manufacturers want to pack as many plates as possible in a given cell, to save space while producing maximum energy density per cubic foot. This packing of the cell jar leaves minimum room for separators. Since the current discharge rate of the cell is improved if the plates are close together, the separator must prevent the plates from contacting each other without impeding electrolyte flow.

Operating temperature

Since battery operation results from chemical reactions, temperature plays a significant part in performance and life. A standard temperature of 77 degrees F (25 degrees C) is used to rate batteries. Some typical derating curves are given in Fig 1.

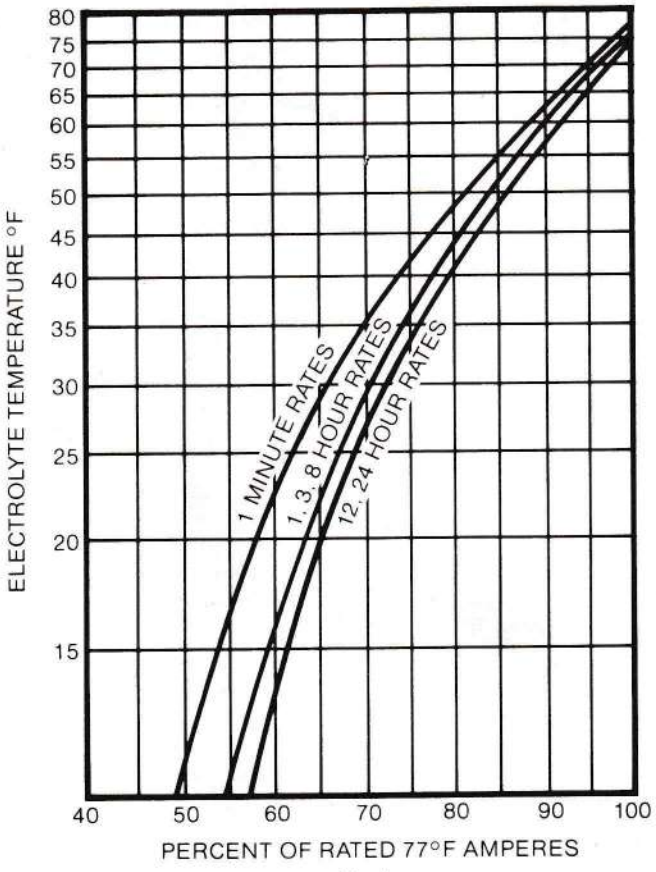


Fig. 1.

Although capacity improves markedly at higher discharge rates as temperature increases, there is a significant deterioration in battery life above 77 degrees F. At 95 degrees F, this deterioration may reach 50%. In lead-antimony batteries the "float current" goes up at a rate of 2 times for each 15 degree F increase in temperature, due to the increase in internal losses, as shown in Fig 2. (Float current is that current which flows in a battery due to the losses in a fully charged cell with a given potential on the plates.) The increase in float current increases grid corrosion and reduces the battery's life expectancy. Table 3 gives various float currents for 100 amp-hour cells with lead-antimony and lead-calcium grids at different potentials.

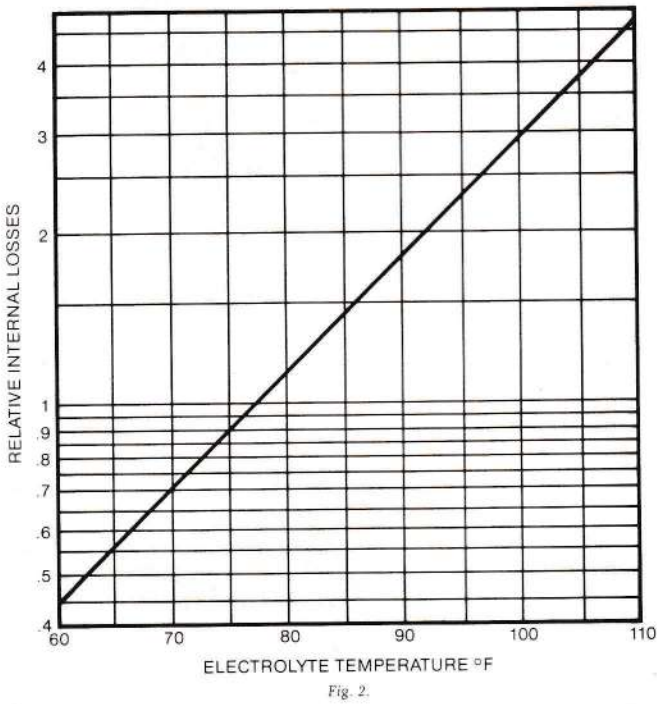


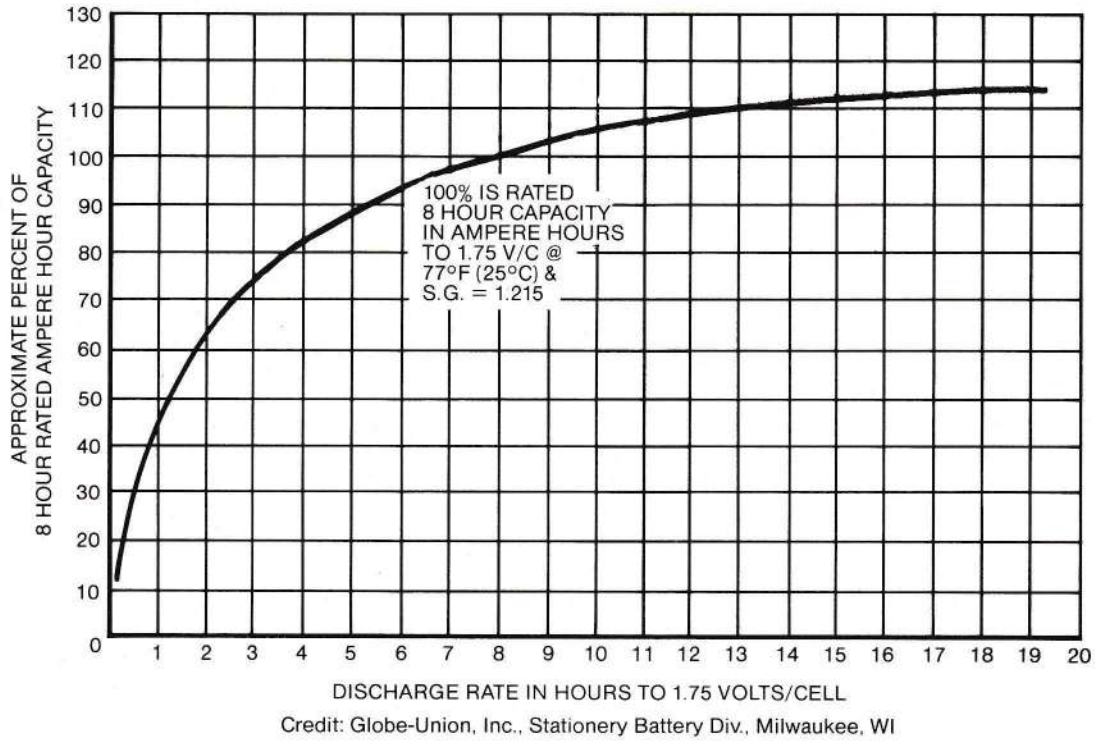
Fig. 2.

Table 3

Float Current for Fully Charged Lead Acid Batteries at a Temperature of 77 Degrees F[3]

Milliamps Per 100 AH Capacity

Per Cell Voltage	New Antimony	Old Antimony	Calcium
2.15	30	120	
2.17	40	160	4
2.20	52	210	6
2.23	75	300	8
2.25	110	440	10
2.27	120	480	12
2.33	200	960	24



Credit: Globe-Union, Inc., Stationery Battery Div., Milwaukee, WI

Fig. 3.

BATTERY APPLICATIONS

Because of the various compromises in battery design, the type of cell which should be used is best determined by the application. Three major types of application, each requiring something different of a battery, are:

(1) Float service, such as communications, UPS, or switchgear

(2) Starting, lighting and ignition (SLI)

(3) Cycle service, such as lift-trucks, material handling equipment, golf carts or other electric vehicles

The application also determines, to a large extent, the recharge requirements.

Float service

In float service a battery is continuously connected across the charging source which normally supplies both any necessary charging current and load currrent. The battery is discharged only when there is a temporary load greater than the charging source can supply or when the AC power fails. (Neither of these occurrences is likely to result in a totally discharged battery, although it's wise to size the battery to allow for such an event, within reasonable expectations and the dictates of economics.)

Antimony, which is a benefit in the cycle service battery, is a decided minus in the float service battery; lead-calcium construction is more desirable.

UPS—Uninterruptible Power Supply—is a combination of battery charger and DC-to-AC inverter used to power critical AC loads which are intolerant of power fluctuation or loss. The battery requirement is unique in that when the AC mains are lost, the battery will contain enough energy to power the inverter for anywhere from 5 minutes to several hours, depending on the size of the inverter. Small UPSs in the 500VA to 15KVA sizes, such as Ratelco manufactures, may have their batteries sized for one to two hours or longer. UPSs which are used to power large mainframe computers are sized to supply power for 5 minutes and even then the batteries are large enough to fill a good-sized room.

This relatively short discharge period requires special consideration in the application. The application is still float service, but the discharge rate changes some of the design requirements. Most batteries are rated at a discharge rate of 8 to 20 hours. If a 100 amp-hour, 8-hour rated battery were to be discharged for 8 hours at a constant current, the results would be

$$\text{I discharge} = \frac{\text{100 amp-hours}}{\text{8 hours}} = 12.5 \text{ amps}$$

Trying to discharge the same battery in 1 hour would *not* produce

$$\text{I discharge} = \frac{\text{100 amp-hours}}{\text{1 hour}} = 100 \text{ amps}$$

because the battery cannot support that amount of discharge in that short a period of time. Instead the battery manufacturer's rating curve must be consulted to see what a particular cell will support. Using the curve in Fig 3,[4] the maximum constant current which

can be supported in the example above is

$$I\ discharge = \frac{100\ amp\text{-}hours \times 47\%}{1\ hour} = 47\ amps$$

If 100 amps were needed to power the inverter for 1 hour the battery would have to be sized:

$$AH = \frac{100\ amps \times 1\ hour}{47\%} = \frac{100}{0.47} = 212.7AH$$

Another consideration in this example: has this discharge constituted a "deep" discharge? Only 47% of the capacity has been used, equivalent to about a 50% discharge since the chemical reaction has had time to work only on the surface of the plates, and the electrolyte has not had all of the lead changed to lead sulfate in the reaction. After allowing the battery cells to stand for a period of time, a hydrometer reading would indicate a partially discharged cell. Because the current was taken out at high "C" rates (where C=amp-hours) the grid structure should have been designed to carry high currents for these periods of time without being overheated due to resistive heating.

Special care must be taken to connect the posts so that there is low loss and little heating. Where maintenance is not done correctly or where acid spills and leakage cause corrosion and poor contact at the battery posts, major damage and losses can occur. It is vitally important to:

(1) Choose a cell design with good acid seals to prevent leakage

(2) Keep the battery clean and the post connections coated with a corrosion-inhibiting compound.

(3) Keep the post connections torqued to the manufacturer's recommendations.

The damage which can result from neglect in any of these areas can be disastrous, especially in high-discharge UPS applications.

Starting, lighting and ignition (SLI)

SLI applications combine several features of both cycle service and float service applications. The SLI battery is discharged only occasionally and then with very few amp-hours removed, but at high discharge rates. The remainder of the time the battery is maintained on a trickle charge sufficient to maintain full charge. Since relatively small amp-hours are used, and deep-discharging is an accident, the plates can be very thin. This allows many plates to be used, with large surface areas exposed to the electrolyte; thus large discharge currents can be drawn from the cell for short periods of time.

This type of cell works well in automotive use where life expectancy is 3 to 5 years. In stationary service economics rule against the SLI battery. It may be acceptable for short-lived stationary projects, but the alternatives should be carefully considered.

Cycle service

In cycle service a fully charged battery is disconnected from the charging source to be put under load. The cell is often totally discharged before it is again connected to a recharging source. This deep cycling of the battery puts high stress on the plates. The chemical composition of the plates changes as the active material changes from lead and lead oxide to lead sulfate during the discharge process. The longer the discharging continues the deeper this chemical change works its way into the plate. Minute stresses set up, causing the active material on the plate to pull away from the grid and shed, falling to the bottom of the cell as mud. These stresses can be accommodated by the grid structure if it is heavy enough and contains enough active material.

Cell design must also compensate for the material which is continually shedding. Thus separators are thicker; there may be a mat which holds the active material in place when it breaks away. "Mud rests" in the bottom of the cell are higher to allow for a greater accumulation of mud without it reaching the point of shorting out the cell. Plates are made relatively thick, and there are fewer of them so that the stresses do not cause warpage and the sulfate has a greater depth to penetrate before causing damage.

The grid material in a cycle-service battery is generally lead-antimony, as a lead-calcium grid has a greater tendency to grow and increase in size with discharge and cannot tolerate deep discharges to the extent that lead-antimony grids can.

CELL SIZING

Various methods are followed to select the proper size cells for a given application. The float service applications of communications, UPS and switchgear are used here as examples.

If the discharge current is relatively constant, the sizing can be relatively simple. The first question to be resolved is the number of cells. As determined earlier, each lead-acid cell has a nominal voltage of 2.0 volts. Although the voltage is relatively stable it may vary from 1.75 volts in its discharged state to 2.35 volts (or higher) during rapid recharge or equalize (see page 10). In a 48-volt communications system this results in a voltage variation of 42 to 56.5 volts for a 24-cell battery. The voltage tolerance of the load must be considered, so that operation can continue until the end voltage is reached or so that the cell can be equalized without damaging the equipment. Various methods may be and are used to restrict the range of operating voltage of the load while getting the most out of the cell; these generally call for end cells or counter EMF (Cemf) cells which are switched in and out depending on load voltage. (These methods are beyond the scope of this discussion, but can be further explored by contacting Ratelco or your local Ratelco representative.) Nickel-cadmium batteries impose an even more stringent voltage requirement on the load, as the voltage range is from 1.0 volt for a discharged cell to 1.55 volts at equalize. For a comparable 48-volt system this is a range of 40 to 62.0 volts for a 40-cell string.

Cell type

The first choice to make is among lead-antimony, lead calcium or nickel-cadmium cells. Table 4 gives a comparison between these types of cell by some of the variables.

Table 4

Comparison of Cell Types

Variable	Lead-Antimony	Lead-Calcium	Nickel-Cadmium
Cycle life	good	fair	excellent
Voltage regulation	fair	fair	poor
Life	15-20 yrs.	20-30 yrs.	20-30 yrs.
Float voltage	2.15-2.20 VPC	2.20-2.25 VPC	1.35-1.45 VPC
Equalize voltage	2.33-2.35 VPC	2.33-2.35 VPC	1.5-1.55 VPC
Water usage	high	low	moderate
Cost	moderate	moderate-plus	high

This comparison indicates that the choice of cell type should depend on the application. If initial cost is the ruling consideration, then lead-antimony is the most reasonable choice; lead-calcium may be 5 to 10% higher in cost. If the application is one where minimum maintenance is important, such as in remote areas, lead-calcium or nickel-cadmium may be the best choice.

As cost is generally very important to most purchasers, the difference between the lead-acid types and nickel-cadmium generally restricts the ni-cad to special applications. Because of cycle-life and longevity advantages the lead-calcium cell is the one usually chosen for stationary service.

Once the type of cell is determined a careful consideration should be made of the construction features of the different manufacturers' products. For instance a significant problem which can result in battery failure is acid leakage. Unless the manufacturer has taken extraordinary care in designing the acid seals, leakage may dramatically reduce battery life, especially in hot, humid climates. Corrosion of the posts and interconnections from acid leakage can lead to failure when the battery is needed most.

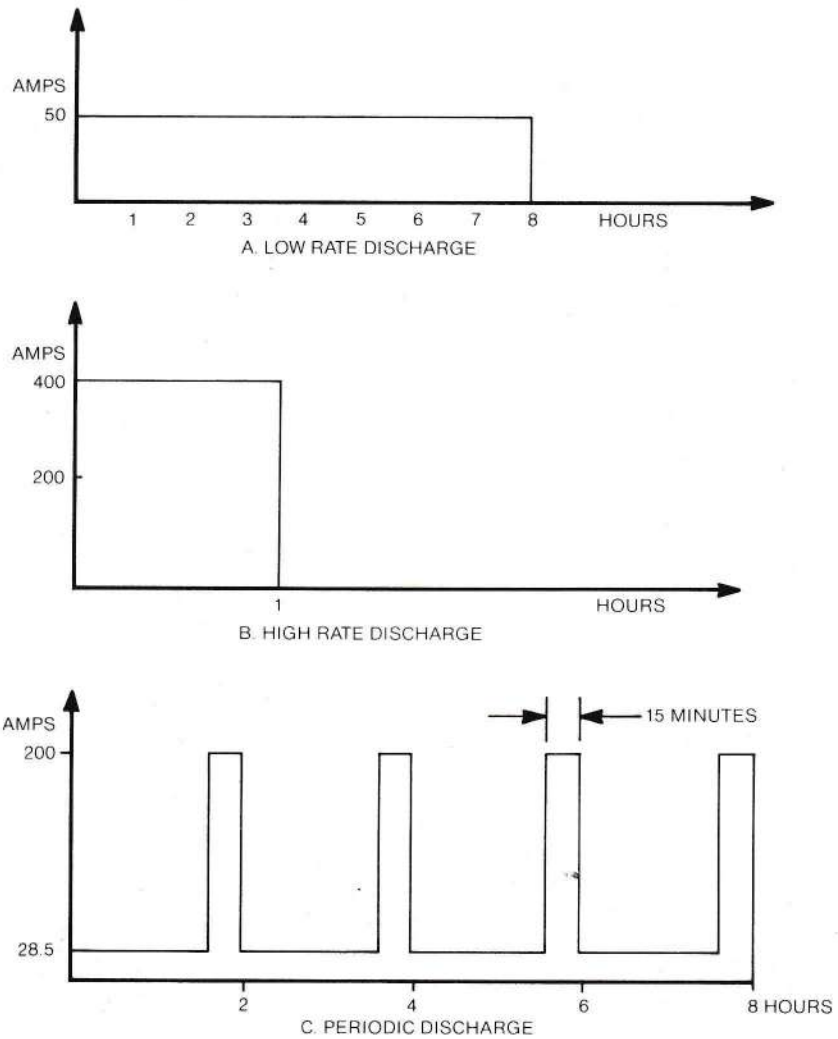


Fig. 4. Battery Discharge Load Profiles

Load profile

Choosing the proper size (capacity) and type of cell will depend to a large extent on load profile. Three sample profiles are given in Fig 4. Each consists of the same amp-hours, but the cell sizing required will be quite different. Profile (a) will require a cell size of approximately 400 amp-hours; (b) will require a cell size of approximately 850 amp-hours; (c) will require a cell size of approximately 550 amp-hours.

Determining the amp-hour capacity required for (4a) and (4b) is relatively straightforward, and every battery manufacturer has literature that will help in determining the cell size required. However, do not assume that the best type of cell for profile (4a) is also the best for (4b). It is generally true that the best choice in terms of performance and cost will be a different cell type for a low-rate than a high-rate discharge.

Determining the cell size for profile (4c) is more complex and quite often requires the aid of a digital computer to choose the most economical, best performing cell. All battery manufacturers will assist in cell sizing and should be consulted in order to assure satisfaction with the installation.

End voltage

End voltage is the minimum voltage that the cell will be allowed to reach during discharge. With rapid discharge rates (less than one hour) the end voltage can be allowed to go as low as 1.60 volts per cell, or even 1.55 volts per cell in some applications. With slower discharge rates the end voltage must be kept higher in order to keep the discharge from destroying the cells. In general the minimum recommended end voltage is 1.75 volts per cell. Requiring a higher end voltage will levy a cell capacity penalty that also depends on the discharge rate. For instance, with a typical battery the penalty for raising the end voltage from 1.75 to 1.90 Vpc ranges from 38% at the one-hour rate to 16% at 8-hour rate. The application should be re-evaluated carefully before an end voltage different than 1.75 volts per cell is chosen.

BATTERY CARE

The most frequent reasons for failure in lead-acid cells are:[5]

(1) sludging of the positive plates

(2) destruction of the positive grid

(3) defects in the negative plate

(4) defects in separators

(5) combinations of the above

Sludging occurs generally in charge-discharge cycle service and is influenced by temperature, current and acid concentration. Less sludging occurs with higher temperature, less current or lower acid concentration.

Negative plates are damaged by sulfation and leading, with sulfation caused by:

(1) long periods of undercharge

(2) continuous high-temperature operation (over 100 degrees F)

Heavy gassing (see below) can remove the fillers used in the paste, causing leading, a compacting of the lead crystals which decreases the capacity.

BATTERY CHARGING

Three of the most popular methods of charging a battery are shown in Fig 5. The object of the recharge is to replace the current that was used as rapidly and economically as possible, while meeting the requirements of any connected load.

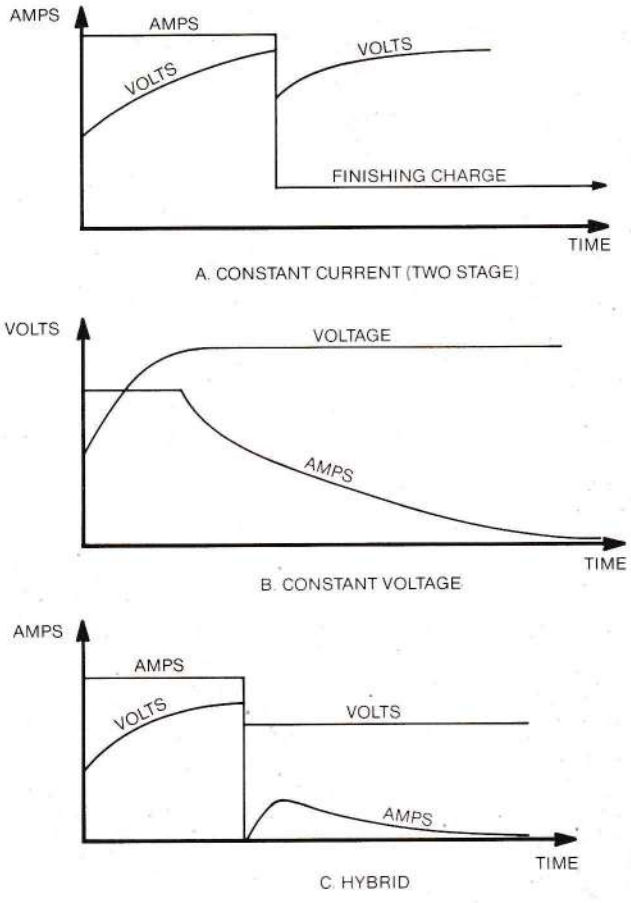


Fig. 5. Battery Charging Methods

RECHARGING WITH CONSTANT CURRENT (Fig. 5A.)

Constant current is a recharging method widely used in the materials handling industry. In its pure state (single stage), a constant current is forced into the battery and the voltage is allowed to rise to any level necessary to accept the current. This is not really practical, because if the charge is being returned at a rate which recharges the battery in the shortest possible time, gassing starts when the recharge is 60-80% complete and rapidly becomes excessive. If the current is reduced at the point where gassing starts, a "finish" charge will complete the recharge at a rate which

does not damage the battery. If the charge is merely stopped at the higher current as gassing starts, the battery will not be fully charged; and should this happen frequently the plates will sulfate, likely producing a permanent loss of capacity. If the cell does not gas on recharge it is a sure sign that the cell is not being fully charged.

If the two-stage constant current recharge is used, there are several methods of determining when to switch rates. One is to sense voltage on the battery and when it has reached a preset point, the charger changes rate; another is to time the recharge and switch at the end of a given time period. The finishing charge can be timed or allowed to continue indefinitely, but a minimum finish charge period must be observed in order to insure the plates do not sulfate.

RECHARGING WITH CONSTANT VOLTAGE (Fig. 5B.)

The constant voltage method is generally used to recharge stationary batteries since so many of them are used in switchgear applications where there is a continuous load of relays, lamps and holding coils, or high intermittent loads such as circuit-breaker tripping; and in communications and UPS applications where large continuous loads are present on a 24-hour-per-day basis.

In switchgear and UPS applications, ripple on the battery has not normally been a problem as the switchgear load or inverter has been insensitive to battery noise. However, in recent years communications and other solid-state control gear has proliferated, where noise is a problem. This requirement for a noise-free environment has produced battery chargers that have ripple figures of 30mvRMS even in switchgear and UPS applications, a requirement which has been common in the communications industry for many years.

In these applications with a continual load and no time to remove the load for recharge, float chargers are used to float the battery and load at a constant voltage.

The only time the battery discharges is with a temporary load peak or when the AC power mains fail. Temporary load peaks normally take only a few amp-hours out of the battery, which are soon returned when the load returns to normal. When the AC power fails, however, it could be for minutes or hours, and the resulting discharge only a few amp-hours or until the battery reaches the end voltage or below. When the AC power returns it is important to restore as much charge as possible in as short a time as possible. If normal float voltage is used to recharge a deeply discharged battery it may take several days before full charge is restored. To get reasonable recharge times the voltage must be increased to a level which would damage the battery if maintained for prolonged periods of time. The voltage may be raised manually or by an equalize timer for a period of 24 to 72 hours, to recharge the battery rapidly without risk of damage.

Recharge voltage

When choosing recharge voltage, consider

(1) speed of recharge

(2) length of applied voltage

(3) load

The amount of time that it takes to recharge a cell is given in Table 5.[6] This table shows that the higher the recharge voltage, the shorter the recharge time—not surprising, except for the length of time it takes to recharge at voltages of 2.15 to 2.20 volts per cell. The open-circuit cell voltage (no current going into or coming out of the cell) is given as

$$Vpc = \text{specific gravity} + 0.84$$

at a temperature of 77 degrees F. For a fully charged cell with a specific gravity of 1.215 this is

$$Vpc = 1.215 \text{ plus } 0.84 = 2.055 \text{ volts.}$$

The difference in applied voltage at 2.15 volts and the open-circuit voltage is quite low, and the recharge time is very long. The recharge voltage can be raised but at some point this is going to have a detrimental effect. Temporarily elevated voltages will not prove detrimental as long as the voltages used do not exceed 2.35 volts per cell and the voltages do not remain elevated more than 50 to 100 hours before being reduced. In the lead-antimony cell this is especially important as the antimony migration to the negative plate causes higher float currents and less capacity.

Table 5

Table of Recharging Times for Stationary Lead-Acid Batteries

% of 8-Hr. AH Discharged	Time to 95% Recharged @ 2.15 v.p.c.	@ 2.25 v.p.c.	@ 2.33 v.p.c.
100%	75 hours	16.6 hours	14.8 hours
90%	73 hours	14.6 hours	13.0 hours
80%	71 hours	13.2 hours	11.7 hours
70%	69 hours	11.2 hours	10.3 hours
60%	67 hours	9.8 hours	8.6 hours
50%	65 hours	8.5 hours	7.1 hours
40%	62 hours	6.6 hours	5.8 hours
30%	55 hours	4.9 hours	4.0 hours
20%	45 hours	3.4 hours	2.5 hours
10%	27 hours	1.6 hours	1.0 hours

The lead-calcium cell does not gas as vigorously as the lead-antimony type and there is no problem of antimony poisoning, but the plates are prone to growing and so prolonged overcharge is not recommended. For lead-antimony cells the float-voltage or continuously applied voltage should be between 2.15 and 2.20 volts per cell; for lead-calcium this voltage can be raised to between 2.20 and 2.25 volts per cell.

Another restriction on recharge voltage is the voltage tolerance of the load. In applications such as golf carts or lift trucks there is no load connected to the battery during recharge, but in other applications, such as communications or switchgear, there is a continual load applied. In these cases the voltage tolerance of the load may be a real limitation on recharge voltage. Then, other means—such as end cells or CEMF cells—can be used to get higher recharge voltages as discussed previously.

Equalization

When the battery is maintained on float for long periods at 2.15 to 2.20 volts the individual cells may become unequal in state of charge. This condition arises from temperature differences between cells, or impurities and minute differences in the cells themselves. Since the applied voltage is so close to the open-circuit voltage of the cells, even minor variations in temperature will cause the condition; in fact a variation of 5 degrees F is sufficient to make a significant difference in the state of charge. Prolonged under-charge will sulfate the plates and cause a permanent loss of capacity, so the battery must have sufficient voltage applied periodically to insure all cells are fully charged. This is called equalization. Equalization may be required whenever the cells differ by more than 0.05 volts per cell from the system average or when the cells vary more than 0.010 in specific gravity. Table 6 gives the recommendations of Globe-Union Inc., Stationary Battery Div., for the charging and equalizing of their stationary batteries. Other manufacturers, recommend a monthly or otherwise regular periodic equalization for 8 to 24 hours at 2.33 volts per cell for lead-antimony cells, with equalization not normally necessary for batteries being floated at above 2.20 volts per cell.

HYBRID CHARGING (Fig. 5C.)

Hybrid charging puts constant current into the battery until the gassing point is reached, at which time the charger switches to a constant voltage for a continuing charge. This form of charging is not widely used. One of the few features that recommend it is that it puts significant charge back into the battery rapidly without causing damage if left connected for long periods. As in two-stage constant current charging, any connected load must not be sensitive to high battery voltages.

Gauging full-charge by specific gravity

The electrolyte in the cell is a mixture of about 30% sulfuric acid in water, giving a specific gravity of about 1.215 in a fully charged battery. As the battery discharges the sulfuric acid is converted to sulfate on the lead plates, and water. The amount of sulfuric acid in the water is the most convenient indicator of the state of charge of the cell. Measuring specific gravity while the battery is charging is not accurate, however, as the change lags behind the charge.

If the electrolyte temperature is not at 77 degrees F, a correction factor of 0.001 must be added to the reading for each 3 degrees F above, or subtracted for each 3 degrees F below, 77 degrees F. This reading should be recorded on a periodic basis and when any of the cells show a specific gravity reading more than .015 points below the average, float equalizing is required. If the average reading drops the float voltage should be adjusted to bring the temperature-corrected specific gravity back to its fully charged value.

Battery gassing

Battery gassing is the changing of water into hydrogen and oxygen gas by current in excess of that being used to charge the cell. During charging the battery must be protected from excesses of gassing and temperature. While gassing is unavoidable, excessive gassing can shorten battery life. This excess current, previously referred to as float current, depends on the voltage being applied to the cell and the plate composition and capacity. The float current approximately doubles for each 0.05 volt increase in voltage.

A formula for the evolution of gasses dependent on float current is found in the paper, IEEE 484-1975, "Recommended Practice for Installation Design and Installation of Large Lead Batteries for Generating Stations and Substations." The equation for the evolution of hydrogen gas per cell is

$$\text{cubic ft/min} = 0.000269 \frac{\text{cu ft}}{\text{minute}} \times \text{I Float}$$

This applies to all lead-acid cells once the float current is known. Table 3 gives the typical float current for 100 AH cells. Different capacity cells will have higher or lower float currents in direct proportion to their capacity.

Gassing does not become significant until the cell has reached at least 70% recharge; it then acts to stir the electrolyte. Fig 6 shows a graphic representation of what occurs with a constant current recharge. When approximately 70% of the charge has been returned to the cell there is a sudden increase in voltage and specific gravity as a result of gassing and the mixing of the electrolyte.

If gassing becomes excessive it will tend to disturb the active material on the plates, causing an increase in shedding and shortening the life of the cell.

As the battery charges, the float current continually electrolyzes water to oxygen and hydrogen gas. This water must be replaced or damage to the cell will result. If the electrolyte level drops to the point where active plate material is exposed the plate will sulfate and cause permanent loss of capacity. Only distilled water should be added to the cell. If impurities are added with the water, performance will eventually suffer.

Battery electrolyte is a mixture of sulfuric acid and water and specific gravity depends on the proportion of sulfuric acid in the electrolyte. When the battery gasses only water is used, thus the remaining electrolyte becomes more concentrated, with a higher specific gravity. Depending on the reservoir capacity, the difference in specific gravity between low and high electrolyte levels can be as much as 30-40 points, e.g. 1.250 instead of 1.215. Don't measure specific gravity

Table 6

Recommended Float and Freshening-Equalize Charging Voltage Per Cell (V/C) vs Specific Gravity.

Specified Specific Gravity (S.G.)	Maximum Allowable Range for AVR V/C Charging	Recommended Average V/C Charging At 77° F	Symptoms When Equalization May be Required				Recommended Freshening-Equalize Charging Voltage Per Cell
			1 Cell Below		10% or More Cells	All Cells	
			V/C	S.G.			
1.210	2.17-2.25	2.20-2.25	2.14	1.195	Fall .010 below the average specific gravity or .04 V/C below the average charging voltage per cell.	Fall .010 below the specified S.G. for the battery.	2.30-2.35
1.215	2.18-2.25	2.21-2.25	2.15	1.200			2.33-2.38
1.225	2.19-2.27	2.22-2.27	2.16	1.210			2.36-2.40
1.250	2.20-2.30	2.25-2.30	2.18	1.235			2.38-2.43
1.300	2.27-2.38	2.33-2.38	2.25	1.285			2.45-2.50

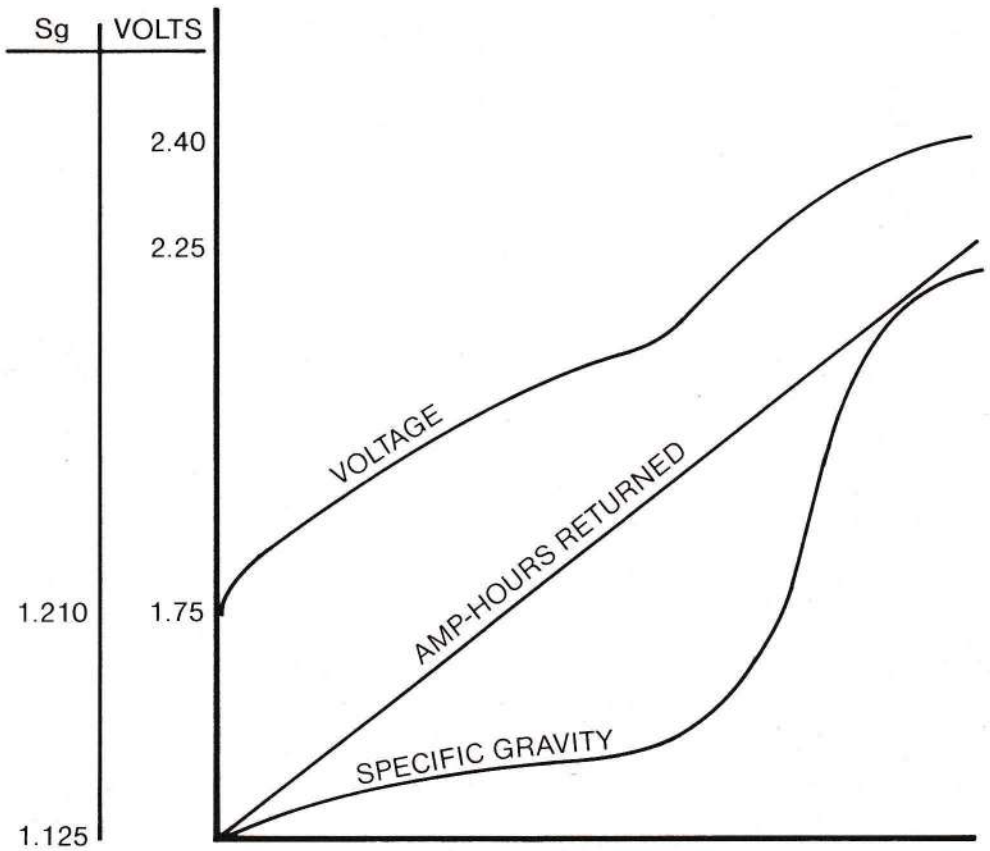


Fig. 6. Recharge Characteristics

immediately after adding water—depending on the rate of gassing, it may take anywhere from one to ten weeks to get complete mixing of the electrolyte.

Temperature

Excessive temperature, created by current flowing in the plates and connectors thru losses, is a more serious problem. The cell will have resistance in the grids and connections between plates and posts. Current flowing into the battery causes heating, and unless the ripple from the charging source is low the heating caused by the charging current may be worse than is readily apparent. The battery acts like a large capacitor of several hundred thousand microfarads, thus ripple current can become quite large. As an example, the ripple current in an SCR charger can reach magnitudes equal to the DC current. This ripple current does not contribute to the recharge of the battery but does increase the losses by up to 50%. DC ammeters will generally read in terms of average amps whereas battery heating depends on the RMS amps. The RMS current can be determined by the use of an RMS reading ammeter or from the equation

$$IRMS = \sqrt{I_{DC}^2 + I_{AC}^2}$$

An example of a 25-amp charger with a typical 25-amp AC current component would be

$$IRMS = \sqrt{25^2 + 25^2} = \sqrt{1250} = 35.35 \text{ amps}$$

which is 41.4% greater than the charging current. This magnitude of ripple current results from a ripple voltage of less than 2%.

The cell temperature rise should not be allowed to exceed approximately 110 degrees F, and under normal recharge will not do so unless the charger current capacity exceeds 25% of the battery amp-hour capacity, or the charging voltage is allowed to exceed normal levels (in excess of 2.35 volts per cell). If the temperature of the electrolyte exceeds 110 degrees F the charging current should be removed.

Cleanliness

Electrolyte is conductive and when spilled on the top of a cell can cause discharge, shock and corrosion. Spilled electrolyte should be wiped up immediately and neutralized with a mixture of bicarbonate of soda and water.

Connections

Batteries are capable of delivering large magnitudes of current, thus loose connections can heat up and melt insulation of the cables connected to the battery as well as the case itself. In emergency discharges, good connections will help to protect the battery and insure long service.

Severe plant and equipment damage resulting from neglected battery maintenance and has occurred several times recently. The potential is so great that Ratelco has developed a device which continuously monitors the battery string and should a condition arise where the battery connections become corroded or loose, an early warning alarm will be given before the condition becomes dangerous. This early warning monitor will be available for shipment in late 1980.

Battery care

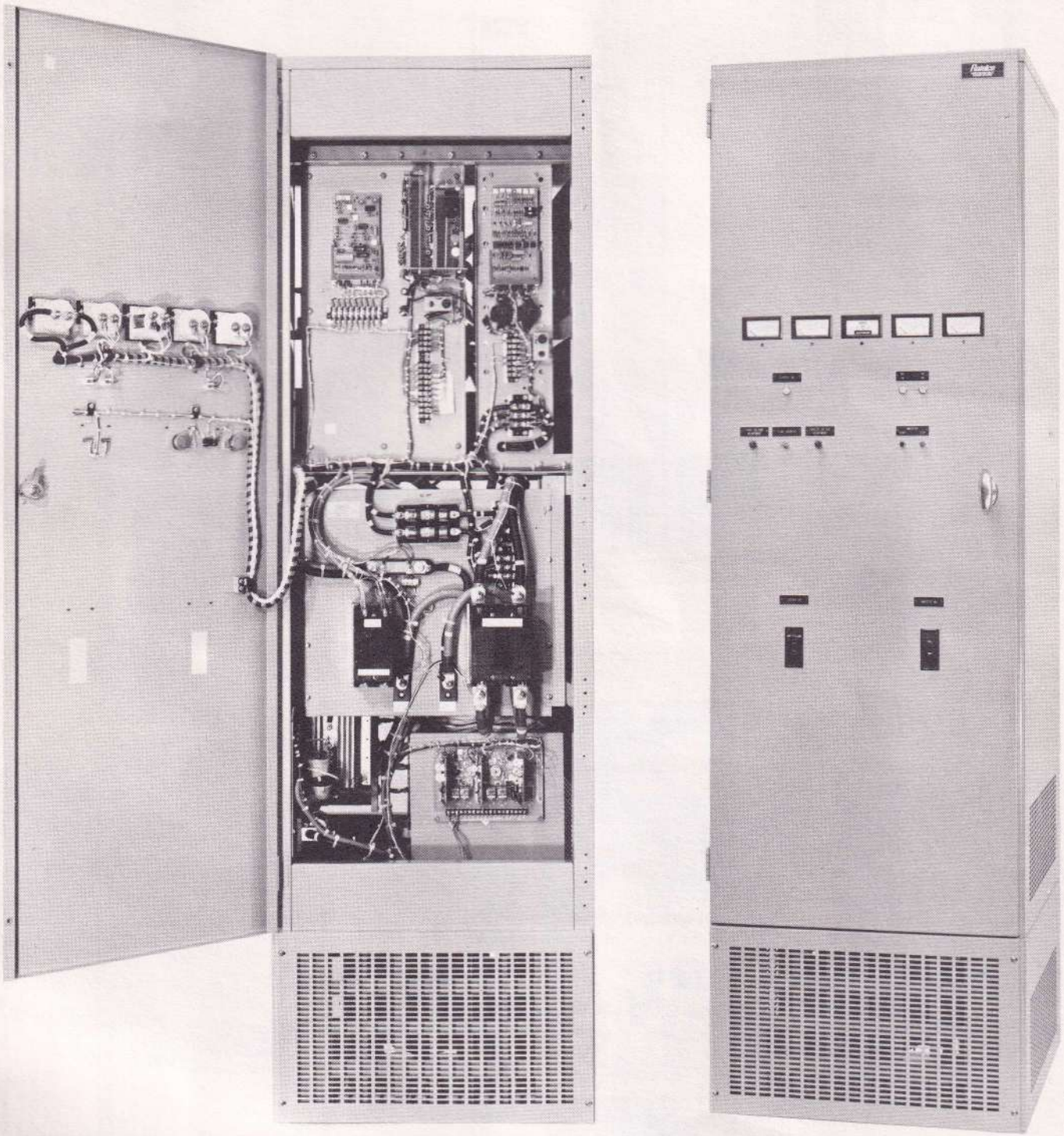
If properly cared for the lead-acid stationary battery will provide years of satisfactory service. The important things to remember are:

(1) Choose the proper type of cell for the given application.
(2) Size the cell for the application using the expertise of the battery manufacturer when in doubt.
(3) Charge the battery properly.
(4) Monitor specific gravity periodically.
(5) Maintain the water level.
(6) Do not allow battery temperatures to reach extremes.
(7) Keep the battery and connections clean and tight.

REFERENCES

1. Charles L. Mantell, *Batteries and Energy Systems* (New York, New York: McGraw-Hill, 1970), p. 108.
2. Hans Bode, translation by R.J. Brodd and Karl V. Kordesch (New York, New York: John Wiley and Sons, 1977), pp. 346-347.
3. Application Note "Gassing and Required Room Ventilation", Globe-Union publication 41-3160.
4. Application Note "Lead-Acid Stationary Batteries Ampere Hour Capacity and Sizing for Single Rate Constant Current Loads", Globe-Union publication 41-3421.
5. Hans Bode, pp. 334-349.
6. Application Note "Exide Stationary Lead-Acid Battery Systems for Industrial and Utility Operations", Exide Power Systems Division publication 7637-1-73.

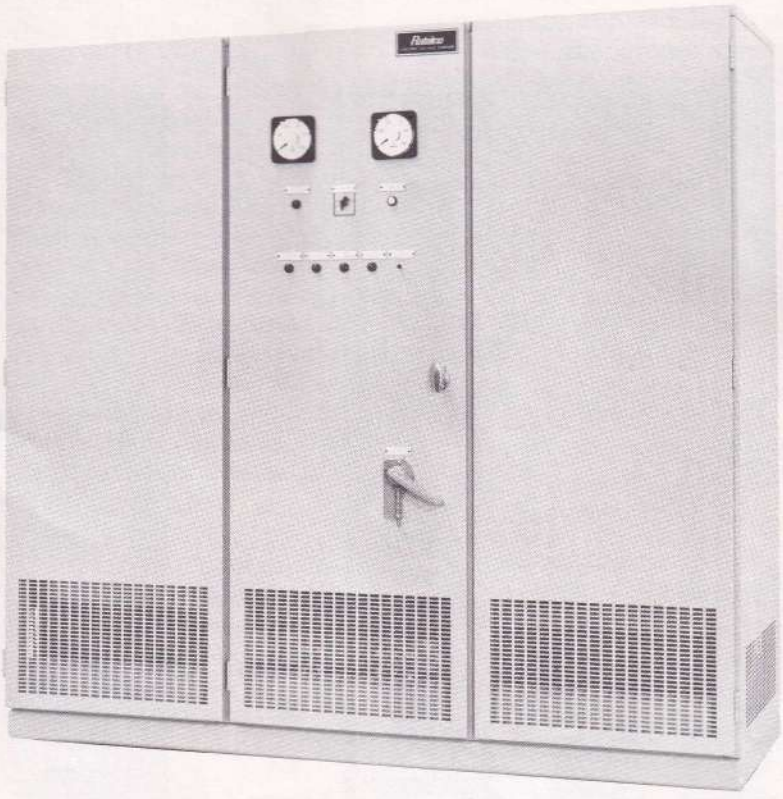
Ratelco Uninterruptible Power Systems

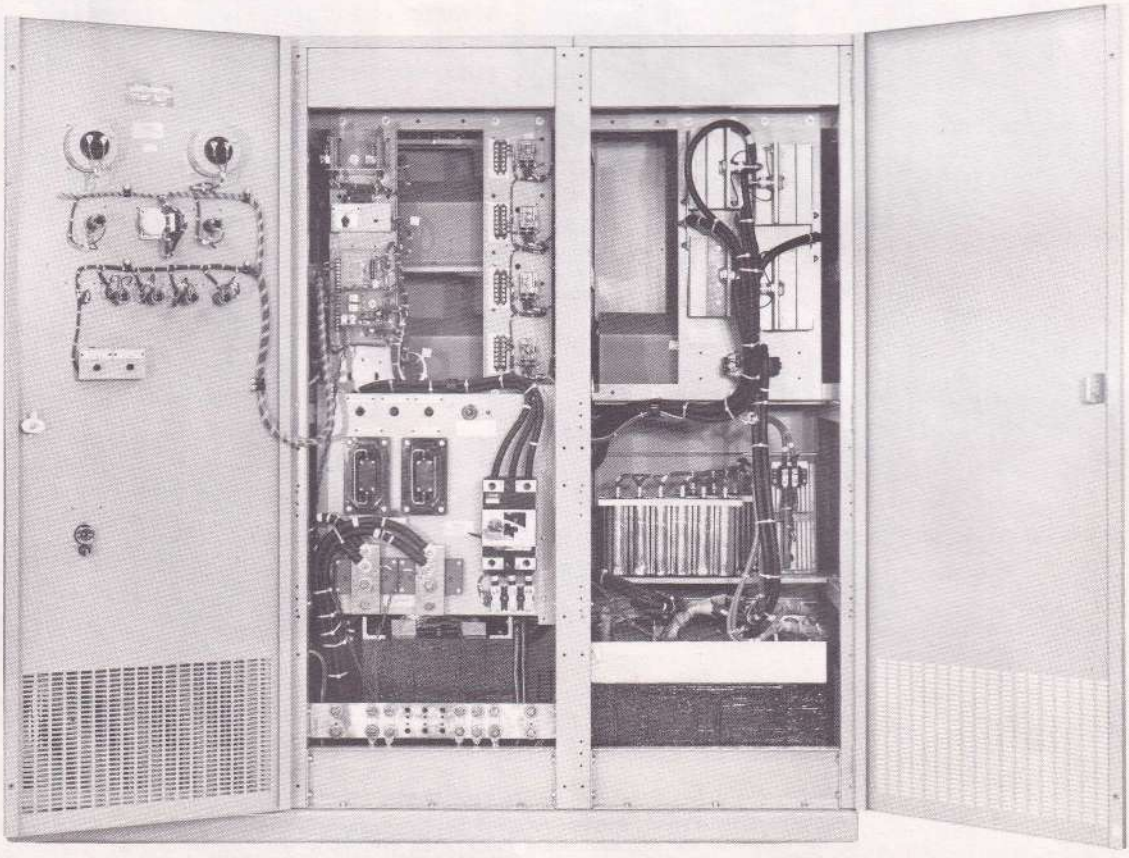


Type FLU5000C7A, 5KVA

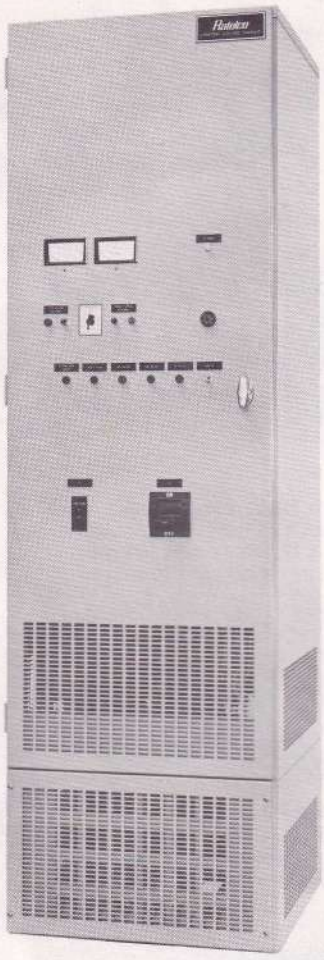
Uninterruptible Power System—designed for the requirements of the computer and communications fields. Used principally to regulate and stabilize AC power and to supply instantaneous power in case of AC failure.

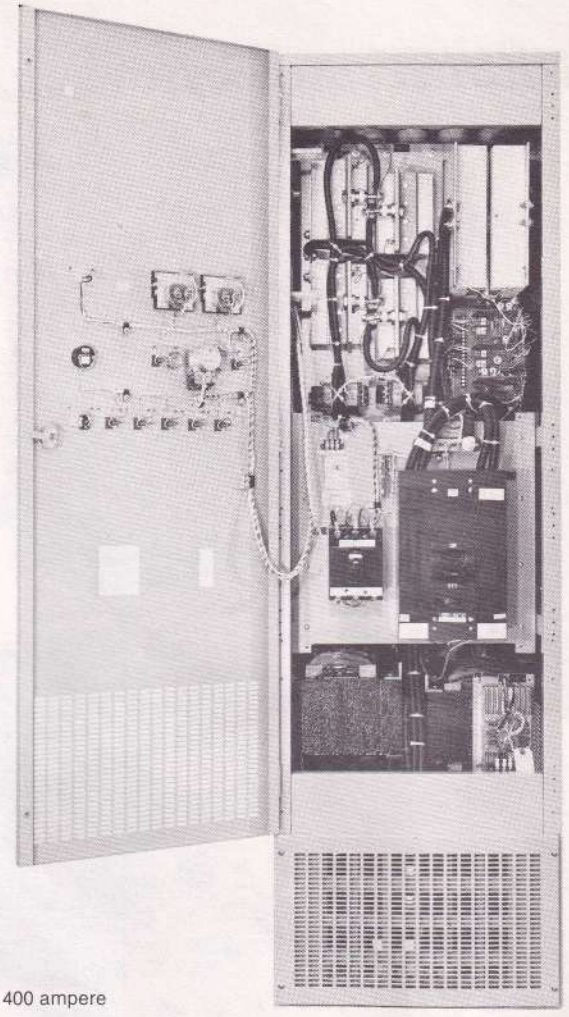
Ratelco Battery Chargers





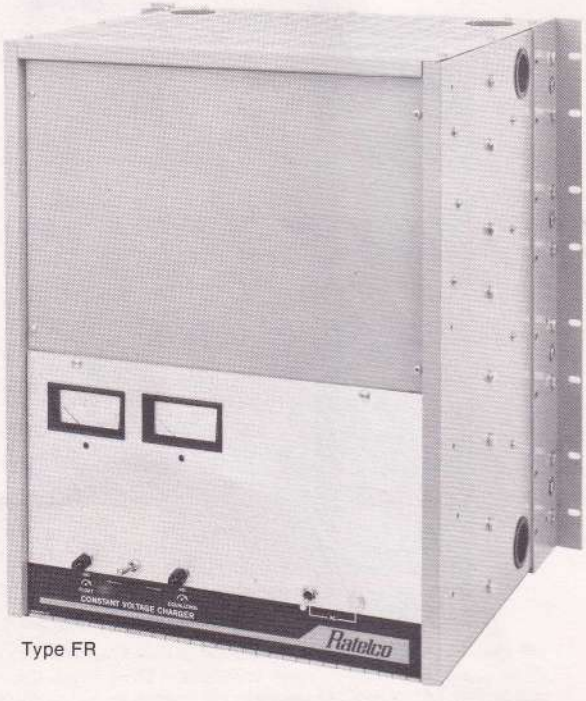
Above – Type FF 1203759, 125 vdc, 375 ampere





Type FF 484007A, 48 vdc, 400 ampere

Type FF



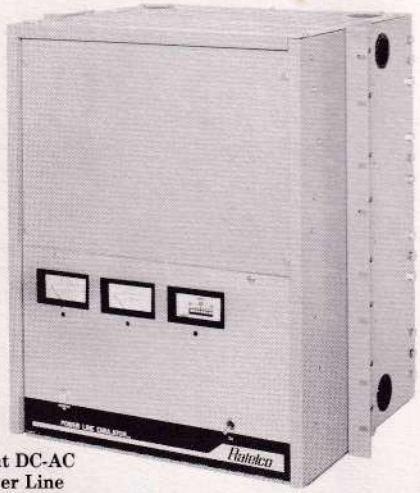
Type FR

Controlled Ferro-Resonant Battery Chargers

One series of battery chargers, the FF series, is designed for communications industries and other installations in which outside interference must be minimized. Filtered to reduce ripple in accordance with the requirements of telemetering, microwave, computer, telephone and radio installations.

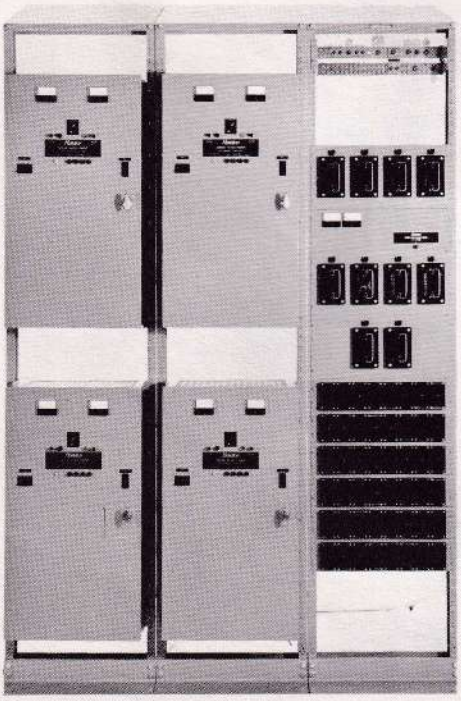
The Type FR series is designed for general industrial and utility applications. Unfiltered chargers for use in installations in which noise is of less consequence such as lighting, alarms, switchgear, railroad service, etc.

Ratelco Accessories

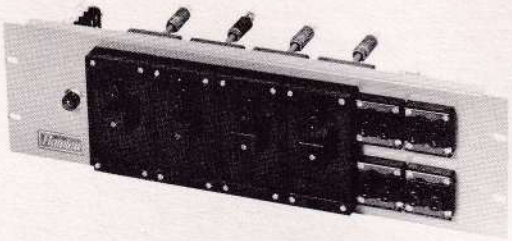


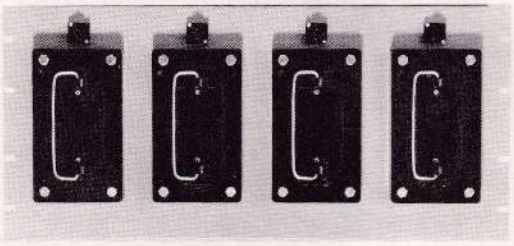
Controlled Ferro-Resonant DC-AC Inverter—Ratelco's "Power Line Emulator"® —designed for use as an AC power source where regular AC power does not exist or is not reliable.

DC Power Supply— the Ratelco well regulated, low ripple power supply. May be used in general bench or laboratory applications such as: testing two-way radios, powering DC to AC inverters and powering integrated circuits.



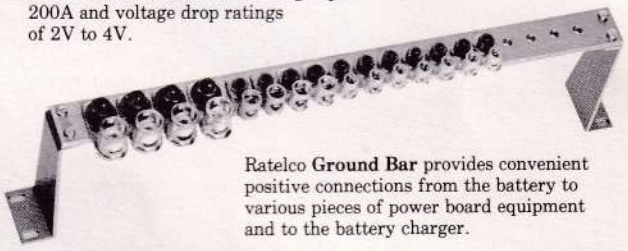
DC Communication Power Equipment Assemblies—Ratelco produces power assemblies in many capacities — 50 amp and up. Each can be supplied with all of the electrical equipment necessary for a finished installation.



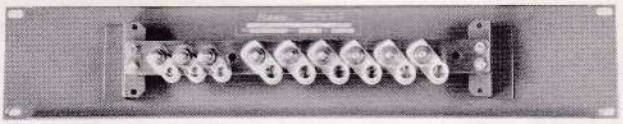


Ratelco **Fuse Panel** is available with various quantities of dead front fuse blocks for fuse ratings of either 0-30A (standard) or 31-60A (must be specified) and type 70 alarm fuse blocks for fuse ratings up to 10A.

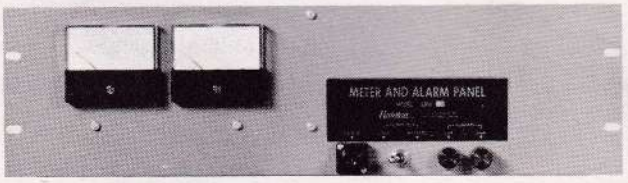
Ratelco **CEMF Cell Panel** is a solid state, dry type DC voltage dropping device available in current ratings up to 200A and voltage drop ratings of 2V to 4V.



Ratelco **Ground Bar** provides convenient positive connections from the battery to various pieces of power board equipment and to the battery charger.



Ratelco **Termination Panel** provides convenient negative connections from the battery to various pieces of power board equipment and to the battery charger.



Ratelco **Meter and Alarm Panel** monitors battery and load voltage, load current, and provide high and low load voltage alarms.

Ratelco **Low Voltage Disconnect Panel** automatically disconnects the load from the battery when the voltage returns.

For more information about any of these Ratelco products, send us the convenient mailing card. ⟶